Notice No.3

Rules for the
Manufacture, Testing and Certification of Materials
July 2020

The status of this Rule set is amended as shown and is now to be read in conjunction with this and prior Notices. Any corrigenda included in the Notice are effective immediately.

Please note that corrigenda amends to paragraphs, Tables and Figures are not shown in their entirety.

Issue date: June 2021

Amendments to	Effective date	IACS/IMO implementation (if applicable)
Chapter 1, Sections 5 & 6	1 July 2021	1 July 2021
Chapter 3, Section 1	1 July 2021	1 July 2021
Chapter 4, Sections 1 & 5	1 July 2021	1 July 2021
Chapter 5, Section 1	1 July 2021	1 July 2021
Chapter 8, Section 1	1 July 2021	1 July 2021
Chapter 9, Section 1	1 July 2021	1 July 2021
Chapter 12, Sections 2 & 4	1 July 2021	1 July 2021
Chapter 13, Sections 1, 2, 4 & 8	1 July 2021	1 July 2021

Chapter 1
General Requirements

■ *Section 5*
Non-destructive examination

5.1 General NDE requirements

5.1.5 It is the manufacturer's responsibility to ensure that all NDE and visual inspections are carried out in a controlled and consistent manner by certified personnel, ~~including~~ in accordance with the approved and applicable NDE procedures, for all methods. This responsibility includes the ~~collating~~ collation of, and provision of accurate reports, which shall be transmitted as appropriate to LR, and in all cases be available upon request to the Surveyor.

5.1.6 NDE testing may be witnessed at the discretion of the LR Surveyor and wherever specifically stated within LR Rules.

5.2 Personnel qualifications

5.2.1 Personnel carrying out non-destructive examination and interpreting the results of non-destructive examination shall be certified to the appropriate level of a nationally recognised scheme. This requirement also extends to advanced methods, which include, but is not limited to Phased Array Ultrasonic Testing (PAUT), Time of Flight Diffraction (TOFD), and digital radiography (RT-D). Schemes such as ISO 9712, ACCP (ASNT Central Certification Program) or SNT-TC-1A fulfil this certification requirement. Other nationally recognised schemes may be acceptable, and shall be agreed with LR. Furthermore, ~~they~~ the personnel shall be certified to the appropriate industry sector for the product type which they are examining.

5.4 Non-destructive examination testing methods

5.4.2 The surfaces under inspection are to be clean, dry and free from scale, oil, grease dirt or paint so that there are no contaminants or entrapped material that may impede the inspection media, especially penetrant media, and are to be free of irregularities that may mask of interfere with interpretation of results.

5.4.3 Visual testing personnel are to confirm that the surface condition is acceptable prior to carrying out any further NDE inspections. Visual testing shall be conducted in accordance with a recognised National or International standard agreed between the Shipbuilder and Surveyor.

5.5 Non-destructive examination procedures and work instructions

(Part only shown)

5.5.1 All non-destructive examinations are to be carried out to a procedure that is representative of the item under inspection. As a minimum the procedures are to be in accordance with the following:

~~(i) Procedures for radiography are to specify the acceptable optical density within the area of interest on the radiograph.~~

~~(j) The minimum optical density within the area of interest on a radiograph is to be equal to or greater than 2,0 for gamma ray and 1.8 for X-ray. A maximum density of 4,0 is acceptable.~~

Existing listed items (k), (l) and (m) have been renumbered (i), (j) and (k).

5.6 Non-destructive examination reports

5.6.1 NDE reports are to include all information required to identify how the examination was executed and are to include the following information where appropriate:

(a) Date of test, and date of test report (if different from test).
(b) Name and qualification of Operator with signatures of the Operator.
(c) Details of the component identification, ship hull number (where applicable), description of test location, purpose of test and volume examined.
(d) Material type, grade, stage of manufacture (where applicable), product form, geometrical configuration, dimensions and thickness.
~~(d)~~ (e) Heat treatment status, where applicable.
~~(e)~~ (f) Weld type, weld location, length of inspected weld, weld process and procedure, and weld configuration, where applicable to welded structures or components. Additionally, for ship hull welds, the number of repairs is to be recorded if a specific area is repaired more than twice.
~~(f)~~ (g) Surface condition and surface test temperature.
~~(g)~~ (h) Test procedure, testing standards, and testing level (as applicable).
~~(h)~~ (i) Equipment used~~.~~, including instrument manufacturer, type of instrument, and any identification numbers (as applicable).
~~(i)~~ (j) Test results with a map or record of reportable and/or reject indications, giving location, datum (and any appropriate coordinate system), dimensions and nature of indications, and a statement of acceptance/non-acceptance, as appropriate.
~~(j)~~ (k) Reference to acceptance criteria and evaluation in accordance ~~to~~ with these criteria.
~~(k) Material type and thickness.~~
(l) Calibration details of the equipment and reference samples, as appropriate to the test method.
(m) Viewing conditions.
(n) Details of software used (where applicable).
(o) Method and values used for range and sensitivity settings (where applicable).

(p) Details of any signal processing and scan increment settings (where applicable).
(q) Access limitations and any deviations from standards or procedures.
(r) Reference to the raw data file(s) (where applicable).

5.6.2 Non-destructive examination inspection records are to be maintained for at least 7 years.

5.7 Liquid penetrant testing

5.7.1 Liquid Penetrant testing (PT) is to be conducted in accordance with ISO 3452-1 or a recognised National or International Standard with the extent of the PT being in accordance with the approved plans and to the satisfaction of the Surveyor.

5.7.2 The temperature of parts examined is to typically be between 5ºC and 50ºC. Outside this temperature range, special high/low temperature penetrant and reference comparator blocks are to be used upon agreement with LR.

5.7.3 In addition to any of the general requirements of *Ch 1, 5.6 Non-destructive examination reports*, PT reports are to include the following specific items:
(a) Type of penetrant, cleaner, and developer used.
(b) Penetration and development timings.
(c) Viewing/lighting conditions.

5.7.4 The PT acceptance criteria for welds are based on the general requirements of ISO 23277 Level 2.

5.8 Magnetic particle testing

5.8.1 Magnetic particle testing (MT) is to be conducted in accordance with ISO 17638 or a recognised National or International Standard with the extent of the MT being in accordance with the approved plans and to the satisfaction of the Surveyor

5.8.2 In addition to any of the general requirements of *Ch 1, 5.6 Non-destructive examination reports*, MT reports are to include the following specific items:
(a) Type of magnetisation.
(b) Magnetic field strength.
(c) Detection media.
(d) Viewing/lighting conditions.
(e) Demagnetisation, if required.

5.8.3 The MT acceptance criteria for welds are based on the general requirements of ISO 23278 Level 2.

5.9 Radiographic testing

5.9.1 Radiographic testing (RT) is to be conducted in accordance with ISO 17636-1 or a recognised National or International Standard with the extent of the RT being in accordance with the approved plans and to the satisfaction of the Surveyor.

5.9.2 Procedures for radiography are to specify the acceptable optical density within the area of interest on the radiograph.

5.9.3 The minimum optical density within the area of interest on a radiograph is to be equal to or greater than 2,0 for gamma ray and 1,8 for X-ray. A maximum density of 4,0 is acceptable if a suitable radiographic film viewer is capable of providing a sufficiently high intensity light source.

5.9.4 In addition to any of the general requirements of *Ch 1, 5.6 Non-destructive examination reports*, RT reports are to include the following specific items:
(a) Type and size of radiation source (width of radiation source), X-ray voltage.
(b) Type of film/designation and number of films in each film holder/cassette.
(c) Number of exposures or radiographs.
(d) Type of intensifying screens where applicable.
(e) Exposure technique, time of exposure and source to film distance.
(f) Distance from radiation source to weld.
(g) Distance from source side of the weld to the radiographic film.
(h) Approximate angle of radiation beam through the weld.
(i) Sensitivity, type and position of IQI.
(j) Optical density.
(k) Geometric un-sharpness.
(l) Specific acceptance class criteria for RT.
(m) Film development process and details.

5.9.5 The control of documentation, unprocessed original images and digitally processed images (where applicable) is to be in accordance with the approved procedure and quality management system.

5.9.6 The RT acceptance criteria for welds are based on the general requirements of ISO 10675-1 Level 2, and Level 3 for Lack of Fusion type defect.

5.10 Ultrasonic testing

5.10.1 Ultrasonic testing (UT) is to be conducted in accordance with ISO 17640 (testing procedure), ISO 23279 (characterisation, where applicable) and ISO 11666 (acceptance levels) or to a recognised accepted National or International standard.

5.10.2 In addition to any of the general requirements of *Ch 1, 5.6 Non-destructive examination reports*, UT reports are to include the following specific items:

(a) Type and identification of ultrasonic equipment used (instrument manufacturer, model and serial number), transducers (instrument manufacturer, serial number, angle and frequency) and type of couplant (brand).
(b) Sensitivity levels calibrated and applied for each transducer.
(c) Amount of transfer loss correction applied and type of reference blocks used.
(d) Signal response used for defect detection.
(e) Indications interpreted as failing to meet acceptance criteria.

5.10.3 For satisfactory quality control, the method of reviewing and evaluating UT reports is to be in accordance with the approved procedure and to the satisfaction of the Surveyor.

5.10.4 The UT acceptance criteria for welds are based on the general requirements of ISO 11666 Quality Level C and Acceptance level 3 and apply to the examination of full penetration ferritic steel welds with thickness from 8 mm to 100 mm. The nominal frequency of transducers/probes is to be between 2 MHz and 5 MHz. Examination procedures for other types of welds, material, thicknesses above 100 mm, assessment of indications not covered in these rules and examination conditions are to be submitted for consideration by LR.

5.10.5 Sensitivity settings/ levels are based on technique 1 of ISO 11666 based on 3 mm diameter side drilled holes and the acceptance criteria for welds are based on the general requirements of ISO 11666 Level 3.

5.11 Advanced NDE methods

5.11.1 Advanced NDE (ANDE) methods may be utilised instead of, or complementary to, existing NDE methods, as applicable and as referenced throughout these Rules. The technical requirements and acceptance standards for each of the methods are described within the appropriate sections of these Rules.

5.11.2 ANDE may be performed, as applicable, on base materials, welds, and components. The acceptance criteria when using ANDE methods shall be the same as for existing NDE methods, unless explicitly stated within the appropriate chapters.

5.11.3 The following terms and definitions for advanced NDE will be referred to hereinafter within these Rules:

- **ANDE**: Advanced non-destructive examination.
- **RT-D**: Digital Radiography (a term for digital radiographic testing and image storage, other than film radiography. This method utilises digital detectors).
- **RT-S** (an RT-D method): Radioscopic testing with digital image acquisition (dynamic ≥12bit). For the purposes of these Rules, this method is taken to mean a digital detector utilising DDAs (digital detector arrays), usually consisting of a flat panel detector (or a series of detectors).
- **RT-CR** (an RT-D method): Testing with computed radiography using storage phosphor imaging plates.
- **PAUT**: Phased Array Ultrasonic Testing.
- **TOFD**: Time of Flight Diffraction (an ultrasonic testing method).
- **AUT**: Automated Ultrasonic Testing/Examination. A technique for ultrasonic examination performed with equipment and search units that are mechanically mounted and guided, remotely operated, and motor-controlled (driven) without adjustments by the technician. The equipment used to perform the examinations is capable of recording the ultrasonic response data, including the scanning positions, by means of integral encoding devices such that imaging of the acquired data can be performed. Furthermore, post-testing image analysis with respect to positional location may be obtained from the captured and stored data.
- **SAUT**: Semi-Automated Ultrasonic Testing/Examination. A technique of ultrasonic examination performed with equipment and search units that are mechanically mounted and guided, manually assisted (driven), and which may be manually adjusted by the technician. The equipment used to perform the examinations is capable of recording the ultrasonic response data, including the scanning positions, by means of integral encoding devices such that imaging of the acquired data can be performed. Furthermore, post-testing image analysis with respect to positional location may be obtained from the captured and stored data.

5.12 Digital radiography

5.12.1 RT-D methods may be of the RT-S (DDA) type or RT-CR type, as applicable to the component or configuration of the test item.

5.12.2 RT-D methods may be used on any material grade and in general on any thickness range, as applicable to the penetrating capability of the radiation energy and the radiation source, and within any limits as identified in the procedure.

5.12.3 All examinations utilising RT-D methods are to be undertaken using an approved procedure. In addition to the general procedural requirements, as specified in *Ch 1, 5.5 Non-destructive examination procedures and work instructions*, procedures for RT-D shall conform to, and specify the following requirements (where applicable):

(a) Technical requirements concerning digital radiography are to be based on ISO 17636-2:2013 and standards referenced therein, or other recognised standards acceptable to LR (upon agreement).
(b) Any variation to applying the standard (e.g. IQI placement of standard or duplex wire IQI) shall be agreed with LR.
(c) The procedure is to include the technical information (as applicable) shown in *Table 1.5.1 Specific requirements of a digital radiography procedure*.

Table 1.5.1 Specific requirements of a digital radiography procedure

Requirement:
Material types or weld configurations to be examined, including thickness dimensions and material product form (castings, forgings, pipe, plate, etc.)
Digitising system description:
Manufacturer and model no. of digitising system
Physical size of the usable area of the image monitor
Film size capacity of the scanning device
Spot size(s) of the film scanning system
Image display pixel size as defined by the vertical/horizontal resolution limit of the monitor
Illuminance of the video display
Data storage medium
Digitising technique:
Digitiser spot size (in microns) to be used
Loss-less data compression technique, if used
Method of image capture verification
Image processing operations
Time period for system verification
Spatial resolution used:
Contrast sensitivity (density range obtained)
Dynamic range used
Spatial linearity of the system
Material type and thickness range
Source type or maximum X-ray voltage used
Detector type
Detector calibration
Minimum source-to-object distance
Distance between the test object and the detector
Source size
Test object scan plan (if applicable)
Image quality measurement tools
Image Quality Indicator (IQI)
Wire image quality indicator
Duplex image quality indicator
Image Identification Indicator
Testing levels, acceptance levels and/or recording levels
Personnel qualification requirements
Surface condition
Records, including minimum calibration data to be recorded
Environmental and Safety issues

5.12.4 The testing class for RT-D methods is to be class B techniques, as per ISO 17636-2. For circumferential weld testing, the minimum number of exposures may correspond to the requirements of class A.

5.12.5 The acceptance standard for steel welds shall be the same as for film radiography and is shown in *Table 13.2.6 Acceptance criteria for radiographic testing.* Further requirements for the examination of welds are specified in *Chapter 13, 2.12 Non-destructive examination of welds.*

5.12.6 The acceptance standard for aluminium welds shall be the same as for film radiography and is shown in *Table 13.8.3 Radiographic acceptance criteria for internal imperfections of aluminium.* Further requirements for the examination of welds are specified in *Chapter 13, 2.12 Non-destructive examination of welds.*

5.12.7 The acceptance criteria for other products, components, or base materials, are to be the same for film radiography (where applicable).

5.12.8 A test report is to be issued for all examinations utilising RT-D methods. In addition to the general reporting requirements, as specified in *Ch 1, 5.6 Non-destructive examination reports*, reports for RT-D additionally record the following information, as applicable:

(a) System of marking used on the test item. Where the nature of the material and/or its service conditions do not permit permanent marking, the location may be recorded by means of accurate sketches or photographs.
(b) Radiation source, type and size of focal spot and identification of equipment used.
(c) Detector, screens, filters (where applicable) and detector basic spatial resolution.
(d) Detector position plan, and source-to-detector distance.

(e) Tube voltage and current, or source type and activity, as applicable.
(f) Exposure duration.
(g) Type and position of image quality indicators (IQIs), including duplex wire IQIs.
(h) Procedural requirements and achieved normalised signal-to-noise ratio (SNR_N) for RT-S, or procedural requirements and achieved grey values and/or SNR_N for RT-CR, as applicable.
(i) For RT-S: type and parameters such as gain, frame time, frame number, pixel size, calibration procedure.
(j) For RT-CR: scanner type and parameters such as pixel size, scan speed, gain, laser intensity, laser spot size.
(k) Image processing parameters used, e.g. of the digital filters.
(l) Details of any software used, such as evaluation software, or defect simulation software (where applicable).
(m) Details of any image magnification or image enhancing parameters within the evaluation software.

5.13 Phased array ultrasonic testing (PAUT)

5.13.1 PAUT may generally be used on any material, configuration, and thickness range, as applicable to ultrasonic testing, and within any limits as identified in the procedure and as per specific requirements in LR Rules.

5.13.2 The following requirements are to be taken into consideration when using the PAUT method:
(a) Depending on the complexity of the item under test and the access to surfaces, there may be a requirement for additional scans and/or complementary NDE techniques to ensure that full coverage of the item is achieved.
(b) PAUT of welds is normally to include an 'E' scan (or linear scan) of the fusion face, together with other scans as defined in the specific test technique. Exceptions to this requirement concerning linear scans are given in *Ch 1, 5.13 Phased array ultrasonic testing (PAUT), 5.13.3 (g)*.
(c) The surface preparation for utilising the PAUT method is to satisfy the requirements for ultrasonic testing. In exceptional cases where there is a requirement to carry out PAUT through paint, the suitability and sensitivity of the test is to be confirmed through an appropriate transfer correction method defined in the procedure. In all cases, if transfer losses exceed 12 dB, the reason is to be considered and further preparation of the scanning surfaces is to be carried out, if applicable. If testing is done through paint, then the procedure is to be qualified on a painted surface.
(d) PAUT method scanning will usually involve the use of AUT or SAUT scanning techniques and equipment. Where this is not possible (perhaps due to the configuration or complexity of the test item), or a specific requirement necessitates manually operated scanning, PAUT manual scanning is permitted on agreement with LR, and the reasons documented why AUT or SAUT cannot be utilised. In all cases, accurate identification of scans and reference to a datum point is required.

5.13.3 All examinations utilising PAUT are to be undertaken using an approved procedure. In addition to the general procedural requirements, as specified in *Ch 1, 5.5 Non-destructive examination procedures and work instructions*, procedures for PAUT shall conform to, and specify the following requirements (where applicable):
(a) Technical requirements concerning PAUT are to be based on ISO 13588, ISO 18563-1, ISO 18563-2, ISO 18563-3, and ISO 19285, and standards referenced therein, or other recognised standards acceptable to LR.
(b) Any variation to applying the standards is to be agreed with LR. When an essential variable in *Table 1.5.2 Specific requirements of a PAUT procedure* changes from the specified value, or range of values, procedure shall require requalification.
(c) When a nonessential variable in *Table 1.5.2 Specific requirements of a PAUT procedure* changes from the specified value, or range of values, requalification of the written procedure is not required.
(d) All changes of essential or nonessential variables from the value, or range of values, specified by the procedure are to require revision of, or an addendum to, the procedure.
(e) The purpose of the testing and the volume to be inspected is to be defined in the testing procedure.
(f) A scan plan is to be provided as part of the procedure, and is to show the beam coverage, probe locations, the weld thickness and the weld geometry.
(g) For techniques involving amplitude-only based evaluation of indications, it is a requirement that an 'E' scan (or linear scan) is to be utilised to scan the fusion faces of welds, so that the sound beam is perpendicular to the fusion face ± 5º. This requirement may be omitted if an 'S' (or sectorial) scan can be demonstrated to verify that discontinuities at the fusion face can be detected and sized, using the stated procedure. This demonstration is to utilise reference blocks containing suitable reflectors in location of the fusion zone.
(h) A reference block shall be used to determine the adequacy of the testing (e.g. coverage, sensitivity setting). The design and manufacture of reference blocks is to be in accordance with ISO 13588 or recognised equivalent standards acceptable to LR.
(i) Indications detected when applying the testing procedure are usually to be evaluated by length and amplitude. Evaluation of indications by length and height are usually for project specific or ECA (Engineering Critical Assessment) requirements and shall be specially agreed with LR.
(j) Indication assessment and acceptance standard for steel welds is to be the same as for ultrasonic testing and is shown in *Table 13.2.7 Acceptance criteria for ultrasonic and phased array testing*, which is equivalent to ISO 19285 and ISO 11666 level 3. Other acceptance criteria may be specially considered by LR upon request.
(k) The sizing techniques include reference levels, Time Corrected Gain (TCG), Distance Gain Size (DGS) and 6 dB drop. 6 dB drop method is only to be used for measuring the indications larger than the beam width.
(l) The procedure is to include the technical information (as applicable), shown in *Table 1.5.2 Specific requirements of a PAUT procedure*.

Table 1.5.2 Specific requirements of a PAUT Procedure

Requirement	Essential Variable	Nonessential Variable
Material types or weld configurations to be examined, including thickness dimensions and material product form (castings, forgings, pipe, plate, etc.)	X	…
The surfaces from which the examination shall be performed	X	…
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	…
Angle(s) and mode(s) of wave propagation in the material	X	…

Search unit type, frequency, element size and number, pitch and gap dimensions, and shape	X	…
Focal range (identify plane, depth, or sound path)	X	…
Virtual aperture size (i.e., number of elements, effective height[1], and element width)	X	…
Focal laws for E-scan and S-scan (i.e., range of element numbers used, angular range used, element or angle increment change)	X	…
Special search units, wedges, shoes, or saddles, when used	X	…
Ultrasonic instrument(s)	X	…
Calibration [calibration block(s) and technique(s)]	X	…
Directions and extent of scanning	X	…
Scanning (manual or automatic)	X	…
Method for sizing indications and discriminating geometric from flaw indications	X	…
Computer enhanced data acquisition, when used	X	…
Scan overlap (decrease only)	X	…
Personnel performance requirements (where required)	X	…
Testing levels, acceptance levels and/or recording levels	X	…
Personnel qualification requirements	…	X
Surface condition (examination surface, calibration block)	…	X
Couplant (brand name or type)	…	X
Post-examination cleaning technique	…	X
Automatic alarm and/or recording equipment, when applicable	…	X
Records, including minimum calibration data to be recorded (e.g. instrument settings)	…	X
Environmental and safety issues	…	X
Note *1*. Effective height is the distance from the outside edge of the first to last element used in the focal law.		

5.13.4 The acceptance criteria for other products, components, or base materials, is to be the same for ultrasonic testing (where applicable).

5.13.5 A test report is to be issued for all examinations utilising PAUT. In addition to the general reporting requirements, as specified in *Ch 1, 5.6 Non-destructive examination reports*, reports for PAUT are to additionally record the following information, as applicable:

(a) Manufacturer, type, frequency of phased array probes including number and size of elements, material and angle(s) of wedges, with identification numbers, where applicable.
(b) Details of reference block(s) with identification numbers, where applicable.
(c) Type of couplant used.
(d) Increment (E-scans), and/or angular increment (S-scans).
(e) Element pitch and gap dimensions.
(f) Focus (calibration should be the same as scanning).
(g) Virtual aperture size, i.e. number of elements and element width.
(h) Element numbers used for focal laws.
(i) Manufacturer documentation on the permitted wedge angular range.
(j) Documented calibration, TCG and angle gain compensation.
(k) Scan plan.
(l) Phased array images of at least those locations where relevant indications have been detected (printed on the report), and additionally, all images and data available in soft copy format.
(m) Reference points and details of the coordinate system.
(n) Details of any software used, including (but not limited to); scan plan set-up and component testing coverage (e.g. ray-tracing software), evaluation software, defect simulation software (where applicable).

5.14 Time of Flight Diffraction (TOFD)

5.14.1 TOFD may generally be used on any material, configuration, and thickness range, as applicable to ultrasonic testing, and within any limits as identified in the procedure and as per specific requirements in LR Rules. Generally, the TOFD method is more limited in its application than PAUT.

5.14.2 The following requirements are to be taken into consideration when using the TOFD method:

(a) Depending on the complexity of the item under test and the access to surfaces, there may be a requirement for additional scans and/or complementary NDE techniques to ensure that full coverage of the item is achieved.
(b) Due to the nature of the TOFD method, there is a possibility that the scan plan may reveal weld volume zones that will not receive full TOFD coverage (commonly known as dead zones, either in the lateral wave, back wall, or both). If the scan plan reveals that these dead zones are not adequately inspected, then further TOFD scans and/or complementary NDE methods are to be applied to ensure full inspection coverage.
(c) The surface preparation for utilising the TOFD method is to satisfy the requirements for ultrasonic testing. In exceptional cases where there is a requirement to carry out TOFD through paint, the suitability and sensitivity of the test is to be confirmed through an appropriate transfer correction method defined in the procedure. In all cases, if transfer losses exceed 12 dB, the reason is to be considered and further preparation of the scanning surfaces shall be carried out, if applicable. If testing is done through paint, then the procedure is to be qualified on a painted surface.

(d) TOFD method scanning will usually involve the use of AUT or SAUT scanning techniques and equipment. Manual scanning is not usually appropriate to the TOFD method due to the nature of the equipment and scanning technique, however, it will be specially considered if demonstrated to be effective for specific applications.

5.14.3 All examinations utilising TOFD are to be undertaken using an approved procedure. In addition to the general procedural requirements, as specified in *Ch 1, 5.5 Non-destructive examination procedures and work instructions*, procedures for TOFD are to conform to, and specify the following requirements (where applicable):

(a) Technical requirements concerning TOFD are to be based on ISO 10863 and ISO 15626, and standards referenced therein, or other recognised standards acceptable to LR (upon agreement).
(b) Any variation to applying the standards is to be agreed with LR. When an essential variable in *Table 1.5.3 Specific requirements of a TOFD procedure* changes from the specified value, or range of values, procedure shall require requalification.
(c) When a nonessential variable in *Table 1.5.3 Specific requirements of a TOFD procedure* changes from the specified value, or range of values, requalification of the written procedure is not required.
(d) All changes of essential or nonessential variables from the value, or range of values, specified by the procedure are to require revision of, or an addendum to, the procedure.
(e) The purpose of the testing and the volume to be inspected is to be defined in the testing procedure.
(f) A scan plan is to be provided as part of the procedure, and is to show the beam coverage, probe locations, the weld thickness and the weld geometry.
(g) A reference block shall be used to determine the adequacy of the testing (e.g. coverage, sensitivity setting). The design and manufacture of reference blocks is to be in accordance with ISO 10863 or recognised equivalent standards acceptable to LR.
(h) Indications detected when applying the testing procedure are usually to be evaluated by length and height.
(i) Indication assessment and acceptance standard for welds is shown in *Table 13.2.8 Acceptance criteria for TOFD testing*, which is equivalent to ISO 15626 level 2. Other acceptance criteria, including project specific or ECA (Engineering Critical Assessment) requirements are to be specially agreed with LR.
(j) The sizing of indications is to be as per the requirements of ISO 10863, or recognised equivalent standards acceptable to LR.
(k) The procedure is to include the following technical information (as applicable), as shown in *Table 1.5.3 Specific requirements of a TOFD procedure*.

Table 1.5.3 Specific Requirements of a TOFD Procedure

Requirement	Essential Variable	Nonessential Variable
Weld configurations to be examined, including thickness dimensions and material product form	X	…
The surfaces from which the examination shall be performed	X	…
Angle(s) of wave propagation in the material	X	…
Search unit type(s), frequency (or frequencies), and element size(s)/shape(s)	X	…
Special search units, wedges, shoes, or saddles, when used	X	…
Ultrasonic instrument(s) and software(s)	X	…
Calibration [calibration block(s) and technique(s)]	X	…
Directions and extent of scanning	X	…
Scanning method (including manual or automatic)	X	…
Data sampling spacing (increase only)	X	…
Method for sizing indications and discriminating geometric from flaw indications	X	…
Computer enhanced data acquisition, when used	X	…
Scan overlap (decrease only)	X	…
Personnel performance requirements, when required	X	…
Testing levels, acceptance levels and/or recording levels	X	…
Personnel qualification requirements	…	X
Surface condition (examination surface, calibration block)	…	X
Couplant (brand name or type)	…	X
Post-examination cleaning technique	…	X
Automatic alarm and/or recording equipment, when applicable	…	X
Records, including minimum calibration data to be recorded (e.g., instrument settings)	…	X
Environmental and safety issues	…	X

5.14.4 Generally, TOFD is not suitable or applicable to cast copper alloys, steel castings, or steel forgings. However, where it is used on steel and aluminium base materials, the acceptance criteria are to be the same for ultrasonic testing (where applicable).

5.14.5 A test report is to be issued for all examinations utilising TOFD. In addition to the general reporting requirements, as specified in *Ch 1, 5.6 Non-destructive examination reports*, reports for TOFD are to additionally record the following information, as applicable:

(a) Manufacturer, type, frequency, element size and beam angle(s) of probes, with identification numbers, where applicable.
(b) Details of reference block(s) with identification numbers, where applicable.
(c) Type of couplant used.
(d) Details of TOFD setups.
(e Scan plan, and details of offset scans (if required).

(f TOFD images of at least those locations where relevant TOFD indications have been detected (printed on the report), and additionally, all images and data available in soft copy format.
(g Reference points and details of the coordinate system.
(f Details of any software used, including (but not limited to) scan plan set-up and component testing coverage (e.g. ray-tracing software), evaluation software, defect simulation software (where applicable).

5.15 ANDE method and procedure qualification

5.15.1 All ANDE is to undergo a qualification and demonstration program to determine the suitability and the effectiveness of the proposed method, for the detection and sizing of discontinuities. The intent of this program is to determine the general capability of the ANDE methods, in demonstrating reasonable equivalence to the existing NDE methods. Project specific requirements may require a more extensive program than described herein.

5.15.2 The extent of the qualification demonstration is dependent upon the method and the complexity of the testing regime, and the components under test.

5.15.3 The following documentation shall be submitted for review:
(a) All technical documentation of the ANDE, including method procedure, history of previous method utilisation and qualification program (where applicable), probability of detection (PoD) capability (where applicable), agreed test samples and/or test blocks used for validation and comparators, and any other technical information to support the qualification programme, as requested by LR.
(b) The operating methodology and detailed extent of utilisation, including all product forms, thickness, and weld configurations (as applicable).
(c) Result of software simulation, where applicable.

5.15.4 Software simulation may be required, where applicable, for PAUT or TOFD techniques. The simulation may include initial test set-up, scan plan, volume coverage, and result image of the artificial flaw. In some circumstances, artificial defect modelling/simulation may be needed or required by the project, and to be agreed with LR.

5.15.5 The procedure qualification test for ANDE methods is to include the following steps (as applicable):
(a) Review of available performance data for the inspection system (detection capability and defect sizing accuracy).
(b) Identification and evaluation of significant parameters, and their variability in determining accurate results.
(c) Planning and execution of a repeatable and reliable test programme, which includes onsite demonstration, as per *Ch 1, 5.15 ANDE method and procedure qualification 5.15.6*.
(d) Documentation of results from the test program, to demonstrate the effective repeatability and reliability of the ANDE method.
(e) The data from the repeatability and reliability test program is to be analysed with respect to the test samples or test blocks, as agreed as part of the qualification program, and is to be presented in a qualification program report.
(f) For PAUT and TOFD, the qualification block should generally satisfy the requirements of *ASME V, Article 14, Mandatory Appendix II (intermediate level)*. Other test blocks may be used upon agreement with LR. If accurate PoD or sizing error distributions need to be evaluated, then the high-level qualification blocks are to be used, as per *ASME V, Article 14, Mandatory Appendix II*.
(g) For PAUT and TOFD, other test samples containing actual defects may also be used to determine method capability and accuracy, in addition to the qualification blocks. These are to be agreed as part of the initial documentation submission for the scope of the procedure qualification program.
(h) The onsite demonstration process shall be witnessed by LR.
(i) The manufacturer is to issue a final report detailing the steps of the qualification program, including all technical details, and results of the ANDE methods with respect to the qualification blocks and test pieces.

5.15.6 An on-site demonstration of the ANDE capability shall be performed, and witnessed by LR, and is to include, where applicable:
(a) Performance demonstration of the proposed ANDE method on the agreed test welds/test pieces/qualification blocks, as appropriate.
(b) For the agreed qualification program test welds, supplementary NDE is to be performed on an agreed proportion of these welds, for cross checking and comparison with proposed and supplementary methods. As an alternative to supplementary NDE cross-checking, other documented reference techniques may be applied for comparison with ANDE results, upon agreement with LR.
(c) Data analysis is to be performed in accordance with the on-site demonstration activities. Where applicable and specially agreed, PoD and sizing accuracy is also to be established.
(d) Where the results of inspection reviews do not conform to the approved procedure, the inspection is to be suspended, and additional qualification and demonstration is to be undertaken to account for any identified nonconformity. This may include additional procedure development and supporting technical information, as applicable.
(e) In such cases where nonconformities are identified, LR may reject the results of ANDE activities until successful demonstration of the method is achieved, and method application is performed successfully.
(f) LR may request a further cross-checking using other NDE methods, should any nonconformities arise either during the qualification program, or application of ANDE methods during normal testing activities.

5.15.7 The procedure qualification shall be considered approved upon successful completion of documentation and report review, data analysis, and witness of on-site demonstration activities, as described in these Rules.

■ *Section 6*
References

6.1 General

(Part only shown)
Table 1.6.1 List of National and International Standards

Rule reference	Standard
Chapter 1 – General Requirements	ISO/IEC 17020 ISO 11666 ISO 17636-1 ISO 17636-2 ISO 17638 ACCP ISO 13588 ISO 18563-1 ISO 18563-2 ISO 18563-3 ISO 19285 ISO 10863 ISO 15626 ASME V ISO 23277 ISO 23278 ISO 23279 ISO 10675-1 ISO 17640 ISO 3452-1
Chapter 13 – Requirements for Welded Construction	~~ISO 9712~~ ISO 25239-3 ISO 25239-4 ISO 25239-5 ISO 6520-1 ~~SNT-TC-1A~~ ~~AWS D3.6M~~ ISO 10042 ISO 5817 ISO 10675-2 ISO 15626

Chapter 3
Rolled Steel Plates, Strip, Sections and Bars

■ *Section 1*
General requirements

1.10 Visual and non-destructive examination

1.10.3 Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*, may be applied to rolled steel components, as appropriate to the material type, thickness, complexity and geometry, in lieu of or complementary to existing NDE methods, as applicable.

Existing paragraph 1.10.3 has been renumbered 1.10.4.

Chapter 4
Steel Castings

■ *Section 1*
General requirements

1.7 Visual and non-destructive examination

1.7.4 Unless otherwise agreed, the accuracy and verification of dimensions are the responsibility of the manufacturer~~.~~, and a report on the relevant examinations is to be submitted to the Surveyor, who may require checks to be made and to witness such checks.

1.7.14 All NDE, including personnel, procedural, test method and reporting criteria are to be in accordance with the requirements of *Ch 1, 5 Non-destructive examination.*

1.7.15 Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*, may be applied to castings, as appropriate to the material type, thickness, complexity and geometry.

1.9 Rectification and dressing of castings

1.9.6 All welding is to be carried out by an approved welder and in accordance with an approved welding procedure which includes the features referred to in *Ch 4, 1.9 Rectification and dressing of castings 1.9.6* to *Ch 4, 1.9 Rectification and dressing of castings 1.9.13*. The welding procedures and welders are to be qualified in accordance with *Ch12 Welding Qualifications*.

■ *Section 5*
Castings for propellers

5.2 Chemical composition

5.2.2 Typical cast steel propeller alloys are given in *Table 4.5.1 Typical chemical composition for steel propeller castings.* Cast steel whose chemical composition deviates from the typical values of *Table 4.5.1 Typical chemical composition for steel propeller castings* shall be specially approved by LR.

5.5 Quality of castings, inspection, and Non-destructive examination

Existing paragraphs 5.5.1, 5.5.2 and 5.5.3 have been deleted in their entirety.

5.5.1 All finished castings are to be 100 per cent visually inspected by the manufacturer. A comprehensive visual examination is to be carried out by the Surveyor.

5.5.2 Castings are to have a workmanlike finish and are to be free from cracks, hot tears, or other imperfections which would be prejudicial to their proper application in service.

5.5.3 Minor casting defects which may still be visible after machining such as small sand and slag inclusions, small cold shuts and scabs are to be suitably removed by mechanical means such as chipping or grinding.

5.5.4 In order to relate the degree of NDE inspection to the criticality of imperfections in propeller blades and to help reduce the risk of failure by fatigue cracking after repair, propeller blades are divided into three severity zones designated A, B and C, as given in *Ch 9, 1.8 Inspection and non-destructive examination*, and *Figure 9.1.2 Severity zones in all propeller blades.* Proposals by the propeller designer for a modified zone area based on detailed hydrodynamic load and stress analysis may be considered by LR in conjunction with the requirements of the *Rules and Regulations for the Classification of Ships, Pt 5, Ch 7, 3.1 Minimum blade thickness 3.1.7* and relevant sections within the appropriate Rules set.

5.5.5 For all propellers, separately cast blades, and hubs, the surfaces covered by severity zones A, B and C are to be subjected to liquid penetrant testing, or magnetic particle testing as appropriate to the material type. Testing of zone A is to be undertaken in the presence of the Surveyor, whilst testing of zone B and C may be witnessed by the Surveyor upon their request.

5.5.6 If repairs have been made either by grinding or by welding, the repaired areas are additionally to be subjected to liquid penetrant testing (or magnetic particle testing, as appropriate) independent of their location and/or severity zone. Weld repairs are, independent of their location, always to be assessed according to zone A.

5.5.7 The surface to be inspected shall be divided into reference areas of 100 cm^2. The indications detected are not, with respect to their size and number, to exceed the values given in *Table 4.5.3 Allowable number and size of relevant indications in a reference area of 100 cm^2*. The area is to be taken in the most unfavourable location relative to the indication being evaluated.

5.5.8 The following definitions apply in relation to the assessment of indications when using the liquid penetrant testing method:

(a) An indication is defined as the presence of detectable bleed-out of the penetrant liquid from the material discontinuities appearing at least 10 minutes after the developer has been applied (*see* Note 1).

(b) Relevant indication: Only indications which have any dimension greater than 1.5 mm shall be considered relevant for the categorisation of indications.

(c) Non-linear indication: an indication with a largest dimension less than three times its smallest dimension (i.e. l < 3 w).
(d) Linear indication: an indication with a largest dimension three or more times its smallest dimension (i.e. l ≥ 3 w).
(e) Aligned indications:

(i) Non-linear indications form an alignment when the distance between indications is less than 2 mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment.

(ii) Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.

Note 1: Where there is uncertainty regarding the dimensions of the bleed-out indication size, either due to a large number of small, grouped indications, or an indication experiences excessive bleed-out, the penetrant testing process shall be repeated by strictly following the procedure.

In exceptional circumstances, whereby the indication size cannot be accurately determined, the actual discontinuity size may be further examined using visual inspection methods, and augmented (if and where necessary) with the aid of magnification instruments, to determine the actual size of the discontinuity, as visible on the surface of the material.

5.5.9 This further examination is to be agreed with the Surveyor, and the Surveyor may, where deemed necessary, request further NDE to ascertain the extent of indications, which may include volumetric testing.

5.5.10 Where required by LR, or deemed necessary by the manufacturer and Surveyor, further volumetric NDE (e.g. radiographic and/or ultrasonic testing) is to be carried out. The acceptance criteria are to be agreed between the manufacturer and LR in accordance with a recognised standard. Note: due to the attenuating effect of ultrasound within austenitic steel castings, ultrasonic testing may not be effective in some cases, depending on the shape/type/thickness, and grain-growth direction of the casting.

5.5.11 Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*, may be applied to steel castings for propellers, as appropriate to the material type, thickness, complexity and geometry, as a substitute for, or complimentary to, conventional ultrasonic or radiographic testing.

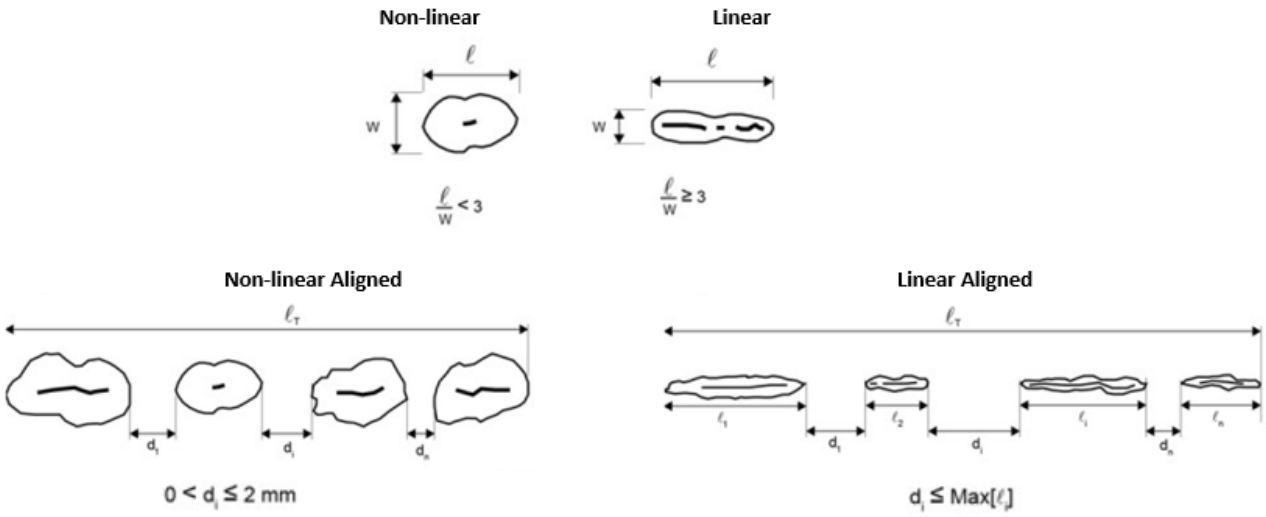
5.5.12 Static balancing is to be carried out on all propellers in accordance with the approved drawing. Dynamic balancing may be necessary for propellers running above 500 rpm.

Table 4.5.3 Allowable number and size of relevant indications in a reference area of 100 cm^2 *(see Note 1)*

Severity Zones	Max. total number of indications	Type of indications (*see* Note 2)	Max. number of each type (*see* Notes 3 and 4)	Max. acceptable value for 'w' or 'l' of indications (mm) (*see* Note 2)
A	7	Non-linear Linear Aligned	5 2 2	4 3 3
B	14	Non-linear Linear Aligned	10 4 4	6 6 6
C	20	Non-linear Linear Aligned	14 6 6	8 6 6

Note 1. The reference area is defined as an area of 0,01 m^2, which may be square or rectangular, with the major dimension not exceeding 250 mm. The area shall be taken in the most unfavourable location relative to the indication being evaluated.

Note 2. Non-linear, linear and aligned indications are defined as follows:



Note 3. Single non-linear indications less than 2 mm in Zone A and less than 3 mm in other zones are not considered relevant.

Note 4. The total number of non-linear indications may be increased to the maximum total number, or part thereof, represented by the absence of linear or aligned indications.

5.6 Rectification of defective castings

5.6.2 Removal of defective material is to be by mechanical means, e.g. by grinding, chipping or milling. The resultant grooves are to be blended into the surrounding surface so as to avoid any sharp contours. Complete elimination of the defect is to be verified by liquid penetrant testing, or magnetic particle testing as appropriate.

5.6.7 Welding procedures are to be qualified in accordance with *Ch 12, 3 Specific requirements for stainless steels* with the following exceptions and additions:

a) Three macro specimens representing the start, middle, and end of test weld are to be prepared and tested. The hardness readings are to be taken from the macro specimen representing the start of weld.
b) The mandrel diameter for bend test should be four times the thickness of test specimen for martensitic stainless steel.
c) The qualification range for base material thickness is given in *Table 4.5.4 Thickness approval range*. The test assembly is to consist of cast material and its thickness should be no less than 15 mm.
d) The qualification is only valid for the base material grade used for the test assembly.
e) Approval for a test made in any position is restricted to that position.
f) The approval is only valid for the welding consumable trade name used in the welding procedure test.

Table 4.5.4 Thickness approval range

Test assembly thickness, *t* (mm)	Thickness range approved
15 < *t* ≤ 30	3 mm to 3*t*
t >30 mm	0,5*t* to 2*t* or 200 mm, whichever is greater

~~5.6.8~~ 5.6.9 After weld repair, the propeller or blade is to be heat treated in such fashion as will minimise the residual stresses. For martensitic stainless steels, this will involve full heat treatment as specified in the approved specification. Special consideration will be given to alternative heat treatment recommended by the manufacturer.

Existing paragraphs 5.6.9 to 5.6.10 have been renumbered 5.6.10 to 5.6.11.

Chapter 5
Steel Forgings

■ *Section 1*
General requirements

1.6 Test material

1.6.5 When required by the conditions of approval for surface hardened forgings (*see Ch 5, 1.5 Heat treatment 1.5.6*) additional test samples are to be processed at the same time as the forgings which they represent. These test samples are subsequently to be sectioned in order to determine the hardness, shape and depth of the locally hardened zone and which of them are to comply with the requirements of the approved specification.

1.8 Visual and non-destructive examination

1.8.13 ~~When required by the conditions of approval for surface hardened forgings (*see Ch 5, 1.5 Heat treatment 1.5.6*) additional test samples are to be processed at the same time as the forgings which they represent. These test samples are subsequently to be sectioned in order to determine the hardness, shape and depth of the locally hardened zone and which are to comply with the requirements of the approved specification.~~ Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*, may be applied to forgings, as appropriate to the material type, thickness, complexity and geometry.

Chapter 8
Aluminium alloys

■ *Section 1*
Plates, bars and sections

1.11 Visual and non-destructive examination

1.11.3 For applications where the non-destructive examination of materials ~~in~~ is considered to be necessary, the extent of this examination, together with appropriate acceptance standards, are to be agreed between the purchaser, manufacturer and Surveyor. Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*, may be applied in lieu of or complementary to existing NDE methods, as appropriate to the material type, thickness, complexity and geometry.

Chapter 9
Copper Alloys

■ *Section 1*
Castings for propellers

1.3 Quality of castings

1.3.1 All castings are to be free from surface or internal defects, including cracks, hot tears or other imperfections, which would be prejudicial to their proper application in service.

1.3.2 Minor casting defects which may still be visible after machining, such as small sand and slag inclusions, small cold shuts and scabs are to be suitably removed by mechanical means such as chipping or grinding.

Existing paragraph 1.3.2 has been renumbered 1.3.3.

1.4 Chemical composition

Table 9.1.1 Chemical composition of propeller and propeller blade castings

Alloy designation	Chemical composition of ladle samples %							
	Cu	Sn	Zn	Pb	Ni	Fe	Al	Mn
Grade Cu 1 Manganese bronze (high tensile brass) Grade Cu 2 Ni-manganese bronze (high tensile brass)	50–57	~~0,1~~ ~~1,5~~ 1,5 max.	33–38	0,5 max.	3,0–8,0	0,5–2,5	0,5–2,0	1,0–4,0
Grade Cu 3 Ni-aluminium bronze	77–82	0,1 max.	1,0 max.	0,03 max.	3,0–6,0 (*see* Note)	2,0–6,0 (*see* Note)	7,0–11,0	0,5–4,0
Grade Cu 4 Mn–aluminium bronze	70–80	1,0 max.	6,0 max.	0,05 max.	1,5–3,0	2,0–5,0	6,5–9,0	8,0–20,0
Note For Naval ships, the nickel content is to be higher than the iron content.								

1.6 Test material

1.6.5 Where the manufacturer propose test specimens to be taken from integrally cast test samples, this is to be the subject of special agreement with LR. Wherever possible, the test samples are to be located on the blades in an area lying between 0,5 to 0,6 *R*, where *R* is the radius of the propeller. The test sample material is to be removed from the casting by non-thermal procedures.

1.8 Inspection and non-destructive examination

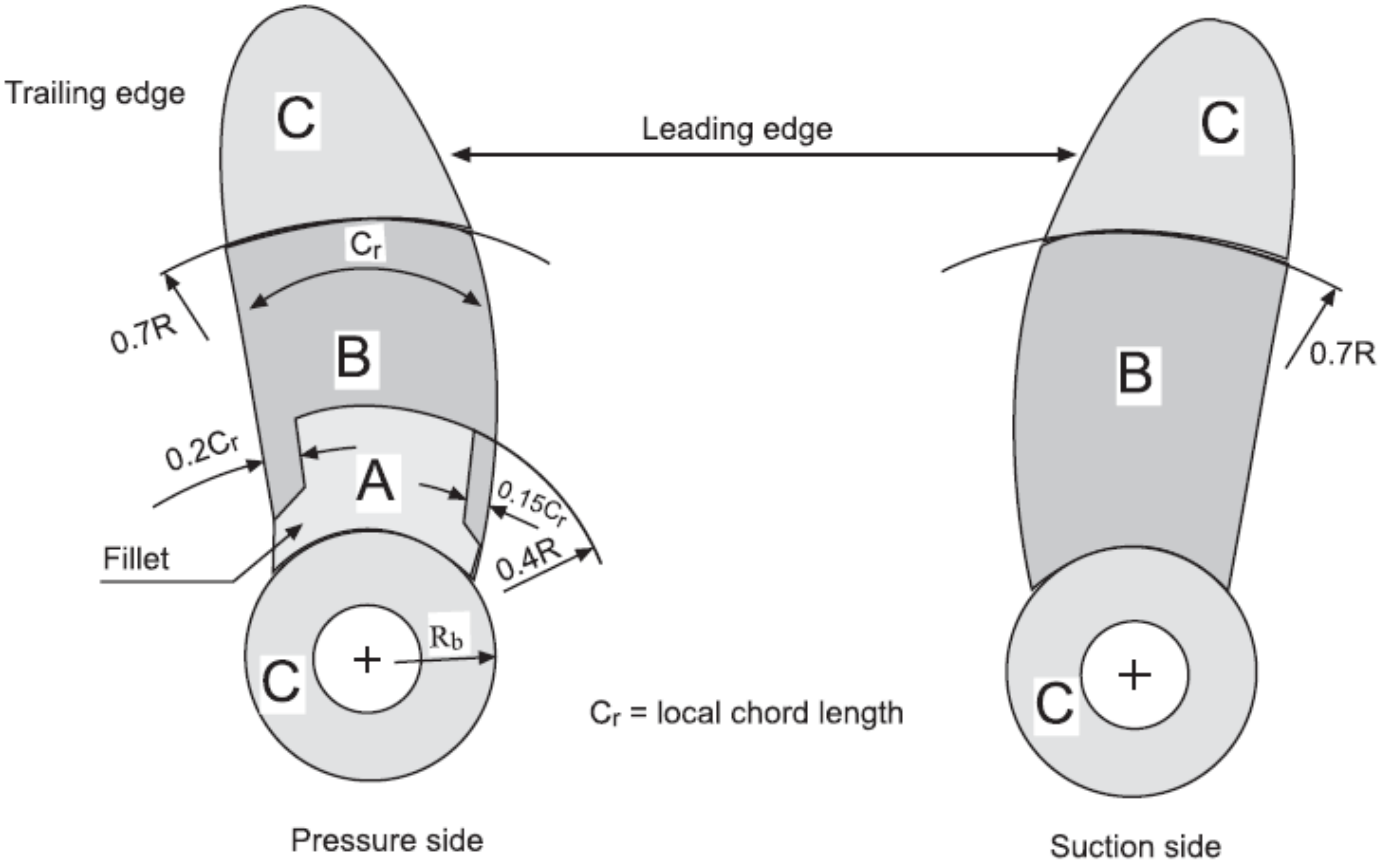
1.8.1 Propeller castings should be visually inspected at all stages of manufacture, and all finished castings are to be 100 per cent visually inspected by the manufacturer. The manufacturer is to draw any significant imperfections to the attention of the Surveyor. Such

imperfections are to be verified in accordance with *Ch 9, 1.9 Rectification of defective castings*.

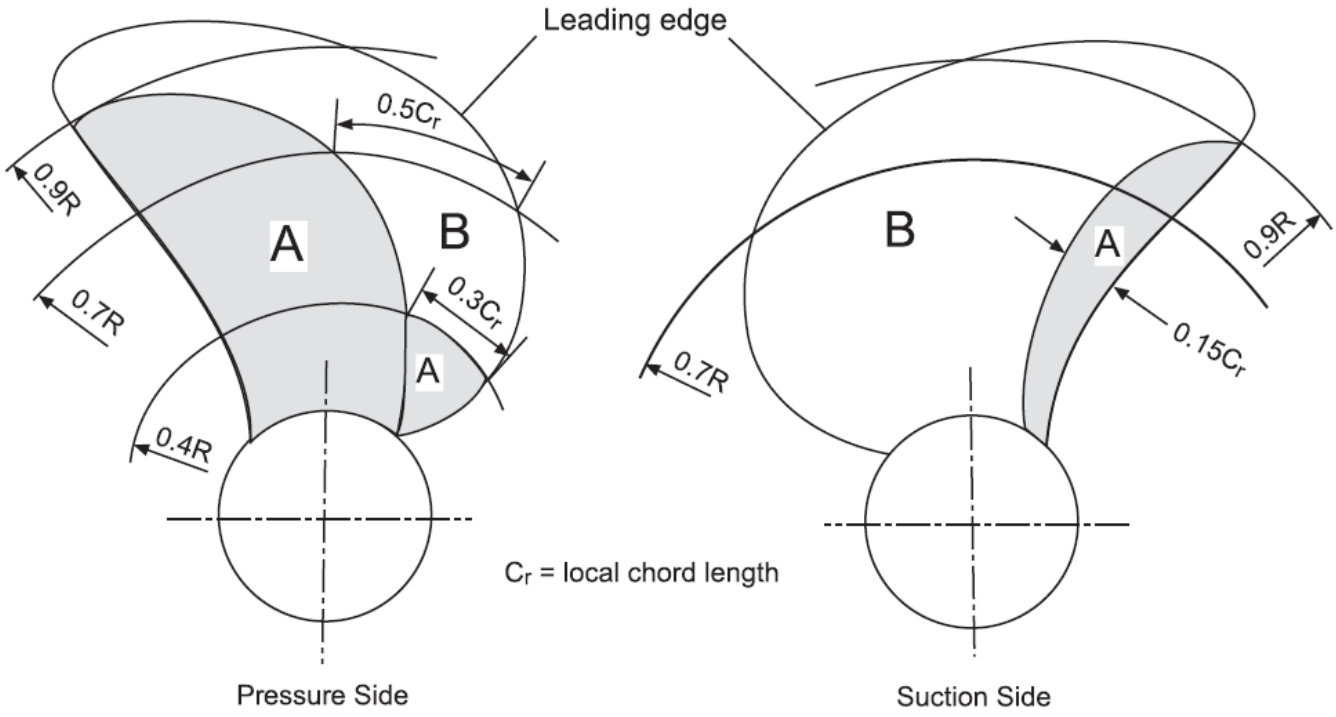
1.8.2 All finished castings are to be subjected to a ~~comprehensive visual examination~~ general visual examination by the Surveyor, in addition to the visual inspection carried out by the manufacturer. ~~including~~This is to include internal surfaces such as the bore and bolt holes. Where unauthorised weld repairs are suspected by the Surveyor, the area is to be etched (e.g. by iron chloride) for the purpose of confirmation.

1.8.3 For the purpose of these requirements, the blades of propellers, including CPP blades, are divided into three severity Zones A, B and C as shown in *Figure 9.1.2 Severity zones in all propeller blades* and detailed in *Ch 9, 1.8 Inspection and non-destructive examination 1.8.4* for blades having skew angles of 25° or less and *Ch 9, 1.8 Inspection and non-destructive examination 1.8.5* for blades having skew angles of greater than 25°. The definition of skew angle is given in the *Rules and Regulations for the Classification of Ships, Pt 5, Ch 7*, *1.1 Plans and particulars, Figure 7.1.1 Definition of skew angle*. Proposals by the propeller designer for a modified zone area based on detailed hydrodynamic load and stress analysis may be considered by LR in conjunction with the requirements of the *Rules and Regulations for the Classification of Ships, Pt 5, Ch 7, 3.1.7 and relevant sections within the appropriate Rules set.*

Existing Figure 9.1.2 has been deleted and replaced with the following;



(a) Blades with propeller skew angles of 25° or less



(b) Blades with propeller skew angles great than 25°

R = Propeller radius
C_r = chord length at radius *r*

Figure 9.1.2 Severity zones in all propeller blades

(Part only shown)

1.8.4 **Skew angles of 25° or less:**

- Zone A is the area on the pressure side of the blade from and including the root fillet to 0,4*R* and bounded ~~by the trailing edge and~~on either side by ~~a~~ lines at a distance 0,15 times the chord length C_r from the leading edge and 0,2 times C_r from the trailing edge, respectively. Where the hub radius (R_b) exceeds 0,27*R*, the other boundary of zone A is to be increased to 1,5R_b.

1.8.10 On completion of machining and grinding, the whole surface of each casting is to be subjected to a ~~dye~~ liquid penetrant inspection in accordance with a procedure acceptable to LR.

1.8.11 All ~~dye~~ liquid penetrant inspections on Zone A areas in the finished condition are to be made in the presence of the Surveyor.

1.8.12 ~~Dye~~ Liquid penetrant inspections on Zones B and C are to be performed by the manufacturer and may be witnessed at the Surveyor's request.

1.8.13 The surface to be inspected shall be divided into reference areas of 100 cm^2. The indications detected shall, with respect to their size and number, not exceed the values given in *Table 9.1.4 Allowable number and size of ~~dye~~ liquid penetrant indications in a reference area of 100 cm^2 ~~(see Note 1)~~*. The area shall be taken in the most unfavourable location relative to the indication being evaluated.

1.8.14 Indications exceeding the acceptance standard in *Table 9.1.4 Allowable number and size of ~~dye~~ liquid penetrant indications in a reference area of 100 cm^2 ~~(see Note 1)~~* shall be repaired in accordance with *Ch 9, 1.9 Rectification of defective castings*.

1.8.16 Where repairs have been made either by grinding, straightening or welding, the repaired areas are to be subjected to ~~dye~~ liquid penetrant inspection in the presence of the Surveyor, regardless of their location and/or severity zone.

1.8.18 Where it is suspected that a casting contains internal defects, or where deemed necessary by the manufacturer or Surveyor, further volumetric NDE should be carried out, where practical, in the form of radiographic and/or ultrasonic ~~examination may be required by the Surveyor~~ testing. ~~.~~ The acceptance criteria are to be agreed between the manufacturer and LR in accordance with a recognised standard. The standard ASTM E272-99 (Severity Level 2) or equivalent is to be the radiographic acceptance standard for copper alloy castings. ~~Ultrasonic testing of Cu 1 and Cu 2 is not considered in these Rules. For Cu 3 and Cu 4, ultrasonic inspection of defects may be possible and is to comply with the requirements for steel castings~~.

1.8.19 Due to the attenuating effect of ultrasound within cast copper alloys, ultrasonic testing may not be effective in some cases, depending on the shape/type/thickness, and grain growth direction of the casting. Generally, ultrasonic testing of Cu 1 and Cu 2 grades is not effective. For Cu 3 and Cu 4, ultrasonic inspection of defects may be possible and effective ultrasound penetration into the casting is to be practically demonstrated on the item. This would normally be determined by way of back-wall reflection, and/or target features within the casting. In the absence of any proposed acceptance standard by the manufacturer, UT acceptance criteria is to comply with the requirements of *Ch 4, 4.6 Non-destructive examination 4.6.2*.

1.8.20 Advanced NDE methods, as described in *Ch 1, 5.11 Advanced NDE methods*d may be applied to Cu 3 and Cu 4 copper alloy castings for propellers, as appropriate to the material type, thickness, complexity and geometry, as a substitute for, or complementary to conventional ultrasonic or radiographic testing.

Existing paragraphs 1.8.19 and 1.8.20 have been renumbered 1.8.21 and 1.8.22.

1.9 Rectification of defective castings

~~1.9.2 The rectification of small indications within the acceptance standard of *Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm2 (see Note 1)* is not generally required except where they occur in closely spaced groups.~~

Existing paragraph 1.9.3 has been renumbered 1.9.2.

~~1.9.4~~ 1.9.3 Where unacceptable defects are found in a casting, they are to be removed by mechanical means, and the surfaces of the resulting depressions are subsequently to be ground smooth. Complete elimination of the defects is to be proved by adequate ~~dye~~ liquid penetrant inspection.

Existing paragraphs 1.9.5 to 1.9.12 have been renumbered 1.9.4 to 1.9.11.

1.9.12 The following definitions apply in relation to the assessment of indications when using the liquid penetrant testing method:

(a) An indication is defined as the presence of detectable bleed-out of the penetrant liquid from the material discontinuities appearing at least 10 minutes after the developer has been applied (*see* Note 1).

(b) Relevant indication: Only indications which have any dimension greater than 1,5 mm shall be considered relevant for the categorisation of indications.

(c) Non-linear indication: an indication with a largest dimension less than three times its smallest dimension (i.e. l < 3 w).

(d) Linear indication: an indication with a largest dimension three or more times its smallest dimension (i.e. l ≥ 3 w).

(e) Aligned indications:

(i) Non-linear indications form an alignment when the distance between indications is less than 2 mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment.

(ii) Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.

Note 1: Where there is uncertainty regarding the dimensions of the bleed-out indication size, either due to a large number of small, grouped indications, or an indication experiences excessive bleed-out, the penetrant testing process shall be repeated by strictly following the procedure.

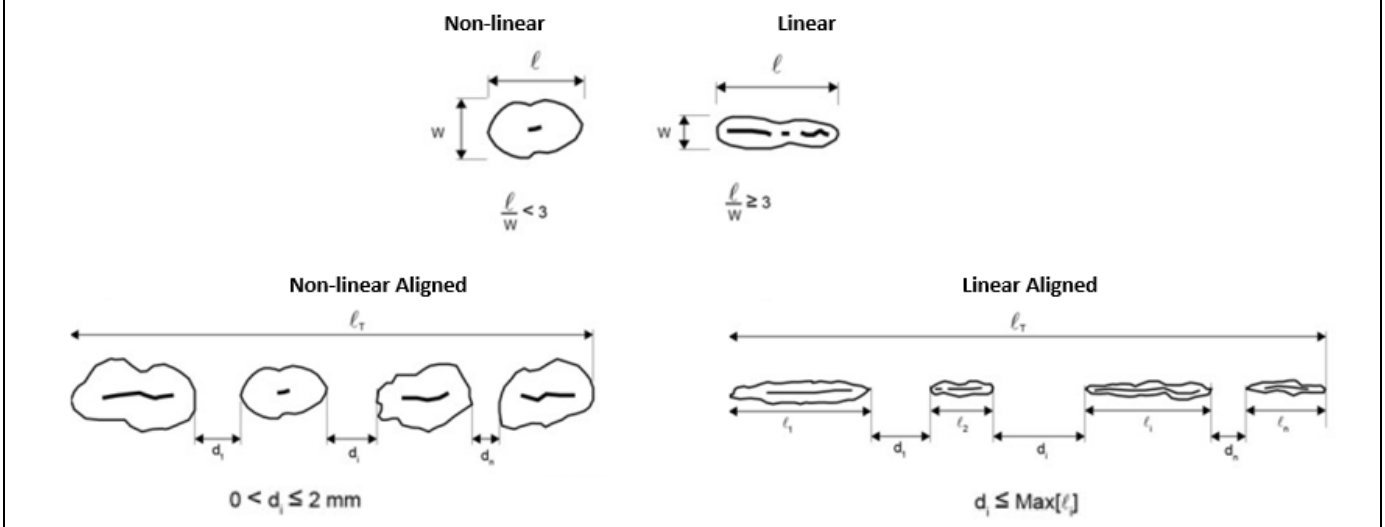
In exceptional circumstances, whereby the indication size cannot be accurately determined, the actual discontinuity size may be further examined using visual inspection methods, and augmented with the aid of magnification instruments, to determine the actual size of the discontinuity, as visible on the surface of the material.

1.9.13 Further examination is to be agreed with the Surveyor, and the Surveyor may, where deemed necessary, request further NDE to ascertain the extent of indications, which may include volumetric testing.

Existing Table 9.1.3 has been deleted and replaced with below;

Table 9.1.4 Allowable number and size of liquid penetrant indications in a reference area of 100 cm^2 (*see* Note 1)

Severity Zones	Max. total number of indications	Type of indications (*see* Note 2)	Max. number of each type (*see* Notes 3 and 4)	Max. acceptable value for 'w' or 'l' of indications (mm) (*see* Note 2)
A	7	Non-linear Linear Aligned	5 2 2	4 3 3
B	14	Non-linear Linear Aligned	10 4 4	6 6 6
C	20	Non-linear Linear Aligned	14 6 6	8 6 6
Note 1. The reference area is defined as an area of 0,01 m^2, which may be square or rectangular, with the major dimension not exceeding 250 mm. The area shall be taken in the most unfavourable location relative to the indication being evaluated. Note 2. Non-linear, linear and aligned indications are defined as follows:				



Note 3. Single non-linear indications less than 2 mm in Zone A and less than 3 mm in other zones are not considered relevant.

Note 4. The total number of non-linear indications may be increased to the maximum total number, or part thereof, represented by the absence of linear or aligned indications.

1.9.14 Areas which are prepared for welding are independent of their location and are always to be assessed according to Zone A. The same applies to the welded areas after being finished by machining or/or grinding.

1.10 Weld repair procedure

1.10.3 Before welding is started, Welding Procedure Qualification tests are to be carried out and witnessed by the Surveyor. Each welder is to be qualified ~~to carry out the proposed welding using the same process, consumable and position which are to be used for the repair.~~in accordance with the requirements of *Ch 12, 5 Welder qualification tests*.

1.10.4 The requirements of *Ch 12, 4.2 Requirements for copper alloys* are to be followed for the welding procedure qualification with the following exceptions and additions:

a) The test assembly should consist of cast material and its thickness should not be less than 30 mm.

b) Bend test may be replaced with fracture test in accordance with ISO 9017. Where fracture test is used, four fracture specimens are to be tested, two extracted from the middle and two from the end of test weld length. The minimum length of each specimen is to be 20 mm and side notches are to be used. Fracture test results are to be assessed in accordance with the acceptance criteria specified for the non-destructive examination in *Ch 12, 2.5 Non-destructive examination (NDE)*.

c) The qualification range for base material thickness is given in *Table 9.1.5 Thickness approval range*.

d) Approval for a test made in any welding position is restricted to that welding position.

e) The approval is only valid for the welding consumable trade name used in the welding procedure test.

Table 9.1.5 Thickness approval range

Test assembly thickness, *t* (mm)	Thickness range approved
t ≥ 30 mm	≥ 3 mm

~~1.10.4~~ 1.10.5 Defects to be repaired by welding are to be removed completely by mechanical means (e.g. grinding, chipping or milling). Removal of defects in accordance with the requirements for Zone A is to be demonstrated by ~~dye~~ liquid penetrant inspection in the presence of the Surveyor. The excavation is to be prepared in a manner which will allow good fusion and is to be clean and dry.

~~1.10.5~~ 1.10.6 Metal arc welding with the electrodes or filler wire used in the procedure tests is to be used for all types of repairs. Welds should preferably be made in the downhand (flat) position. ~~Where necessary, suitable~~ Suitable preheat is to be applied before welding, and the preheat temperature is to be maintained until welding is completed.

Existing paragraphs 1.10.6 to 1.10.15 have been renumbered 1.10.7 to 1.10.16.

Existing Table 9.1.5 has been renumbered Table 9.1.6.

1.11 Straightening

1.11.1 The extent and procedure of straightening is to be agreed with the Surveyor.

1.11.2 Static loading is to be used for hot and cold straightening of propeller.

1.11.3 Weld repaired areas may be subject to hot straightening, provided that it can be demonstrated that weld properties are not impaired by the hot straightening operations.

1.11.4 Hot straightening of a bent propeller blade or a pitch modification is to be carried out after heating the bent region and approximately 500 mm wide zones on either side of it to the temperature range given in *Table 9.1.7 Hot straightening temperatures*.

1.11.5 The heating for hot straightening is to be slow and uniform and the concentrated flames such as oxyacetylene and oxypropane should not be used. Sufficient time is to be allowed for the temperature to become uniform through the full thickness of the blade section. The temperature is to be maintained within the suggested range throughout the straightening operation. A thermocouple instrument or temperature indicating crayons is to be used for measuring the temperature.

1.11.6 Cold straightening may be used for minor repairs of tips and edges of propeller blades. Cold straightening on CU1, CU2 and CU4 bronze is to be followed by a stress relieving heat treatment in accordance with *Table 9.1.6 Soaking times for stress relief heat treatment of copper alloy propellers*.

Table 9.1.7 Hot straightening temperatures

Alloy Type	Hot straightening temperature °C
CU1	500 - 800
CU2	500 - 800
CU3	700 - 900
CU4	700 - 850

~~1.11~~ 1.12 Identification

~~1.11.1~~ 1.12.1 Castings are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all castings which have been accepted:

a) Identification mark which will enable the full history of the item to be traced including the manufacturer's mark.
b) Alloy grade.
c) LR or Lloyd's Register and the abbreviated name of LR local office.
d) Personal stamp of Surveyor responsible for the final inspection.
e) Date of final inspection.
f) Skew angle if in excess of 25°. *See Pt 5, Ch 7, 1 Plans and particulars* of the ~~Rules for Ships~~ *Rules and Regulations for the Classification of Ships* for the definition of skew angle.
g) The number of the test certificate.
h) Ice class symbol, where applicable.

~~1.12~~ 1.13 Certification of materials

~~1.12.1~~ 1.13.1 An LR certificate is to be issued for each propeller, *see Ch 1, 3.1 General*.

~~1.12.2~~ 1.13.2 The manufacturer is to provide the Surveyor with the following particulars for each casting:

a) Purchaser's name and order number.
b) Description of casting~~.~~, to include diameter, number of blades, pitch, direction of turning, and drawing number.
c) Alloy designation and/or trade name~~.~~, and chemical composition of each heat.
d) ~~Identification number of casting.~~ Heat or casting number.
e) Cast identification number if different from (d).
f) Details of heat treatment, where applicable.
g) Skew angle if in excess of 25°. *See* the relevant Rules for the definition of skew angle.
h) Final weight of casting.
i) Results of non-destructive tests and details of test procedures.
j) Proportion of alpha-structure for Cu1 and Cu2 alloys.
k) Results of mechanical tests.
l) A sketch showing the location and extent of welding repairs (if any).
m) Shipbuilding project number, if known.

Chapter 12
Welding Qualifications

■ *Section 2*
Welding procedure qualification tests for steels

2.5 Non-destructive examination (NDE)

2.5.3 For welds with specified yield strength ~~up to 400~~ less than 420 N/mm^2, and with carbon equivalent less than or equal to 0.41 percent, NDE may be performed as soon as the test assembly has cooled to ambient temperature. For other steels, NDE is to be delayed for a period of at least 48 hours after the test assembly has cooled to ambient temperature.

■ *Section 4*
Welding procedure tests for non-ferrous alloys

4.2 Requirements for copper alloys

(Part only shown)

Table 12.4.10 Range of approval for copper alloy material grades

Category	Alloy grade used in the qualification test	Alloy grades approved
Propellers	CU1	CU1
	CU2	CU1 and CU2
	CU3	~~CU1, CU2 and~~ CU3
	CU4	CU4 ~~see~~ *see* Note 1

Chapter 13
Requirements for Welded Construction

■ *Section 1*
General welding requirements

1.11 Non-destructive examination of welds

1.11.1 Non-destructive examinations are to be made in accordance with approved written procedures and shall comply with the general NDE requirements as per ~~*Ch 1 5.1 General NDE requirements* of the *Rules for the Manufacture, Testing and Certification of Materials Ch 1, 5 Non-destructive examination*~~.

1.11.2 Non-destructive examinations are to be undertaken by qualified personnel as per ~~*Ch 1, 5.1 General NDE requirements*~~ *Ch 1, 5.2 Personnel qualifications.* of the *Rules for the Manufacture, Testing and Certification of Materials*.

1.11.7 For welds in steels with specified yield strength ~~up to 400~~ less than 420 N/mm^2, and with carbon equivalent less than or equal to 0,41 per cent, NDE may be performed as soon as the test assembly has cooled to ambient temperature. ~~For other steels, NDE is to be delayed for a period of at least 48 hours after the test assembly has cooled to ambient temperature.~~ For the steels shown in *Table 13.1.1 Cooling times prior to non-destructive examination* the following cooling times are to be observed prior to the application of non-destructive examination to completed welding.

Table 13.1.1 Cooling times prior to non-destructive examination

Type of steel	Cooling time prior to applying NDE (after all welds have reached ambient temperature and after any applicable post weld heat treatment)
Specified Yield strength < 420 N/mm^2 and CE ≤ 0,41	On welded structure reaching ambient temperature

420 N/mm^2 ≤ Specified Yield strength ≤ 690 N/mm^2	Not before 48 hours after completion of welding
Specified Yield strength > 690 N/mm^2	Not before 72 hours after completion of welding
Note *1*. At the discretion of the Surveyor, the 72 hour interval may be reduced to 48 hours for radiographic or ultrasonic inspection, provided there is no indication of delayed cracking, and a complete visual and random magnetic particle or penetrant inspection to the satisfaction of the Surveyor is conducted 72 hours after welds have been completed and cooled to ambient temperature. **Note** *2*. Regardless of yield strength, consideration is to be given to requiring a delayed inspection where evidence of delayed cracking has been observed in production welds. **Note** *3*. At the discretion of the Surveyor, a longer interval and/or additional random inspection at a later period may be required, for example, in case of high thickness welds.	

1.11.16 In general, start/stop points in welds made using automatic welding processes (i.e. welding in which all welding operations are performed without welding operator intervention during the process and manual adjustment of welding parameters by the welding operator is not possible) are to be examined using radiographic or ultrasonic inspection, except for internal members where the extent of testing is to be agreed with the Surveyor.

1.11.17 Consideration may be given for a reduction in inspection frequency for welds where volumetric inspection and the quality assurance techniques applied indicate satisfactory quality.

1.11.18 Where the Surveyor becomes aware that an NDE location has been repaired without a record of the original defect, the shipyard is to carry out additional examinations on areas adjacent to the repaired area, to the satisfaction of the Surveyor.

1.11.19 Where PWHT is carried out the requirement for testing after a delay period may be relaxed, at the discretion of the Surveyor.

1.15 Rectification of weld defects

1.15.1 Where repairs are extensive the manufacturer is to investigate the reason for the defects and take the necessary actions to prevent recurrence. In addition, consideration is to be given to the sequence of repairs and to providing temporary supports to prevent misalignment or collapse. When unacceptable indications are found, additional areas of the same weld length are to be examined unless it is agreed with the Surveyor and the manufacturer that the indication is verified as being isolated.

1.15.10 All radiographs exhibiting non-conforming indications are to be brought to the attention of the Surveyor, and such welds are to be repaired and re-inspected as required by the procedures and the test plans. When non-conforming indications are observed at the end of the radiograph, additional radiographic inspection will generally be required to determine their extent. As an alternative measure, the manufacturer may, upon agreement with the Surveyor, excavate and repair the affected welds to fully determine the extent of defects.

1.15.11 The manufacturer is to monitor and record the repair rate and take such corrective actions as are required and identified by the Quality Assurance system.

■ *Section 2*
Specific requirements for ship hull structure and machinery

2.12 Non-destructive examination of steel welds

Existing Table 13.2.5 has been deleted and replaced with below;

Table 13.2.5 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing

<table>
<tr><th rowspan="2">Surface discontinuity</th><th rowspan="2">Classification according to ISO 6520-1</th><th colspan="2">Acceptance Criteria</th></tr>
<tr><td colspan="2">Visual inspection</td></tr>
<tr><td>Crack</td><td>100</td><td colspan="2">Not accepted</td></tr>
<tr><td>Lack of fusion</td><td>401</td><td colspan="2">Not accepted</td></tr>
<tr><td>Incomplete root penetration in butt joints welded from one side</td><td>4021</td><td colspan="2">Not accepted</td></tr>
<tr><td rowspan="3">Surface pore</td><td rowspan="3">2017</td><td colspan="2">Visual inspection</td></tr>
<tr><td colspan="2">Thickness (t)</td></tr>
<tr><td>t = >0,5 – ≤ 3,0 mm</td><td>t = > 3,0 mm</td></tr>
<tr><td>Not permitted</td><td>Butt welds: d = ≤ 0,2 t (max. of 2,0 mm)
Fillet welds: d = ≤ 0,2 a (max. of 2,0 mm)</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>See Notes 4, 5, & 6.</td></tr>
<tr><td></td><td></td><td colspan="2">Liquid penetrant inspection</td></tr>
<tr><td></td><td></td><td colspan="2">Single pore indication diameter d ≤ 6 mm see Notes 1, 2, 3 & 4.</td></tr>
<tr><td></td><td></td><td colspan="2">Magnetic particle inspection</td></tr>
<tr><td></td><td></td><td colspan="2">Single pore diameter d ≤ 3 mm see Notes 1, 3 & 4.
d = major axis of dimension</td></tr>
<tr><td rowspan="4">Undercut</td><td rowspan="4">5011 (Continuous)

5012 (Intermittent)</td><td colspan="2">Thickness (t)</td></tr>
<tr><td>t = >0,5 – ≤ 3,0 mm</td><td>t = > 3,0 mm</td></tr>
<tr><td>Short imperfections only:
h ≤ 0,1 t</td><td>Short imperfections only:
h ≤ 0,1 t (max 0,5 mm)</td></tr>
<tr><td colspan="2">Smooth transition to parent material is required and imperfection is not to be regarded as systematic.</td></tr>
<tr><td colspan="4">Note 1. A pore is defined as an indication having a length less than or equal to three times its width.
Note 2. A penetrant indication refers to the size of the bleed out from the discontinuity resulting in the indication.
Note 3. Indications that are approximately in line, which are separated by less than the length of the smaller indication, are to be considered as a single indication.
Note 4. d = diameter.
Note 5. t = thickness of thinner material.
Note 6. a = Throat thickness.
Note 7. h = Height or width of imperfection.</td></tr>
</table>

2.12.4 In addition to visual inspection, where required by either LR Rules, the NDE checkpoint plan, the contract inspection and test plan, or as warranted for further testing either by the manufacturer or the surveyor, welded joints are to be examined using any one or a combination of ultrasonic, radiographic, magnetic particle, eddy current, dye penetrant or other acceptable methods appropriate to the configuration of the weld.

2.12.5 The method to be used for the volumetric examinations of welds is the responsibility of the builder~~.~~, however, the following technical considerations shall be noted for the choice concerning the selected method: ~~Radiography is generally preferred for the examination of butt welds of 8 mm thickness or less. Ultrasonic testing is acceptable for welds of 8 mm thickness or greater and is to be used for the examination of full penetration tee butt or cruciform welds or joints of similar configuration. Advanced ultrasonic techniques, such as Phased Array Ultrasonic Testing (PAUT), may be used as a volumetric testing method in lieu of radiography or manual ultrasonic testing. If these methods are used, the thickness limitations for manual ultrasonic testing apply.~~

(a) For full penetration butt welds, the use of advanced NDE (ANDE) methods may be used in lieu of (or complementary to) existing ultrasonic or radiographic testing methods. These methods may additionally be used on other weld configurations, with some limitations, as specified in *Table 13.2.9 Applicable methods for testing of materials and weld joints*.

(b) Radiography (using film or RT-D methods) may be used for the examination of welds for any thickness range, as applicable to the penetrating capability of the radiation energy and the radiation source, and within any limits as identified in the procedure in order to achieve the specified quality level. The applicable material and joint types are given in *Table 13.2.9 Applicable methods for testing of materials and weld joints*.

(c) Ultrasonic testing may be used for the examination of welds, generally for 8 mm thickness or greater, and advanced methods (such as PAUT or TOFD) for thicknesses of 6 mm or greater (as appropriate). The applicable material and joint types are given in *Table 13.2.9 Applicable methods for testing of materials and weld joints*.

(d) Where there is a requirement for enhanced NDE acceptance criteria to be applied to thick plate sections in the hatch coaming region of container ships, as per the Measure 3 requirement in *Table 8.2.1 Preventative measures to be used in design and construction for thick steel plates*, as described in *Pt 4, Ch 8, 2.3 Requirements for use of thick steel plates 2.3.10*, the UT and PAUT acceptance criteria are to be derived from the *ShipRight Procedure for the Use of Enhanced NDE in Container Ships*. This derived acceptance criteria are project specific, and the acceptance criteria stated in *Table 13.2.7 Acceptance criteria for ultrasonic and Phased Array testing* is not applicable.

Existing paragraph 2.12.6 has been replaced with:

2.12.6 The acceptance criteria for volumetric weld testing as applied to the appropriate methods are given in the following tables:

(a) Radiographic testing (including RT-D): *Table 13.2.6 Acceptance criteria for radiographic testing.*

(b) Ultrasonic testing and PAUT (based on length and amplitude of indications): in *Table 13.2.7 Acceptance criteria for ultrasonic and Phased Array testing.*

(c) TOFD testing (based on length and height of indications): *Table 13.2.8 Acceptance criteria for TOFD testing*. *See also Figure 13.2.5 General scheme for acceptance conditions* for the general approach to acceptance/rejection and interpretation of signal parameters. Other acceptance criteria, including project specific acceptance criteria, are to be specially agreed with LR.

Existing Table 13.2.6 has been deleted and replaced with below;

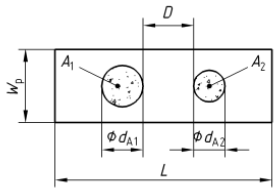
Table 13.2.6 Acceptance criteria for radiographic testing

Discontinuity	Classification according to ISO 6520-1	Acceptance criteria
Crack	100	Not permitted
Lack of fusion	401	Acceptable up to but only intermittently and not breaking the surface, $\sum l \leq 25$ mm, $L = 100$ mm
Lack of penetration	402	Not permitted
Slag inclusions, Flux inclusions, & Oxide inclusions	301, 302 & 303	$h < 0{,}3\ s$ (max. 3,0 mm) $\sum l \leq s$, (max. 50 mm) $L = 100$ mm *See* Notes 1, 2, 4, 5 & 10.
Porosity & Gas pore (Single Layer)	2011 & 2012	$A \leq 1{,}5$ % $d \leq 0{,}3\ s$ (max. 4,0 mm) $L = 100$ mm *See* Notes 1, 2, 3, 4, 5 & 10.
Porosity & Gas pore (Multi-Layer)	2011 & 2012	$A \leq 3{,}0$ % $d \leq 0{,}3\ s$ (max. 4,0 mm) $L = 100$ mm *See* Notes 1, 3, 5, 6 & 10.
Linear porosity	2014	$d \leq 0{,}3\ s$ (max. 3,0 mm) $L = 100$ mm *See* Notes 1, 3, 5, 6 & 10.
Clustered (localised) porosity	2013	$dA \leq W_p$ (max. 20 mm) $L = 100$ mm *See* Notes 1, 3, 5, 6, 10 & 11.
Elongated cavity & wormholes	2015 & 2016	$h < 0{,}3\ s$ (max. 3,0 mm) $\sum l \leq s$, (max. 50 mm) $L = 100$ mm *See* Notes 1, 2, 4, 5, 8 & 10.
Shrinkage cavity (other than crater pipes)	202	Not permitted
Crater pipe	2024	Not permitted
Metallic inclusions other than copper	304	$l \leq 0{,}3\ s$, (max. 3,0 mm) *See* Note 2
Copper inclusions	3042	Not permitted

Note *1*. L = Length of indication (mm).
Note *2*. l = Length of indication (mm).
Note *3*. A = Sum of projected areas of indications related to L x W_p, in %.
Note *4*. h = Width of indication, the width or height of surface imperfection (mm).
Note *5*. s = Nominal Butt weld thickness (mm).
Note *6*. d = Diameter of pore (mm).
Note *7*. W_p = Width of weld or cross surface imperfection (mm).
Note *8*. $\sum l$ = Summary length of imperfections within L (mm).
Note *9*. If the length of the weld is below 100 mm then the maximum length of indications is not to exceed 25% of that weld.
Note *10*. For details regarding the sum of acceptable areas for porosity, *see* *Figure 13.2.2 Sum of acceptable areas for radiography*.
Note *11*. *dA + Diameter of Pore envelope*

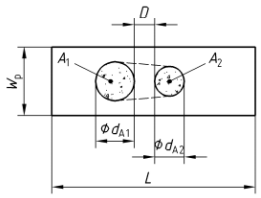
Sum of acceptable areas

Clustered porosity, $D > d_{a2}$



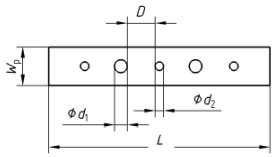
The sum of the different pore areas related to the evaluation area $L \times W_p$

Clustered porosity $D < d_{a2}$



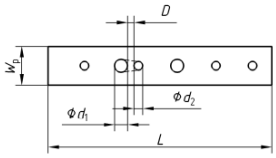
If D is less than d_{a1} or d_{a2}, whatever is smaller, an envelope surrounding the porosity area $A_1 + A_2$ shall be considered as one area.

Linear porosity, $D > d_2$



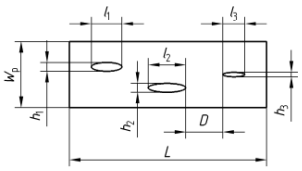
The sum of the different pore areas ($D_1^2\ \pi / 4\ +\ d_2^2\ \pi / 4\ +\ $) related to the evaluation area $L \times W_p$

Linear porosity, $D < d_2$



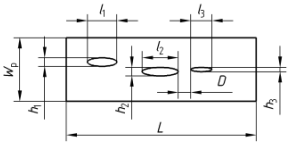
If D is smaller than the smaller diameter of one of the neighbouring pores, the full connected area of the two pores is to be taken into the sum of imperfections

Elongated cavities and wormholes $D > l_3$



The sum of the length of indications $\sum l$ shall be determined for each testing length

Elongated cavities and wormholes $D < l_3$



If D is smaller than the shorter length of one of the neighbouring imperfections, the full connection of the two imperfections is to be taken into the sum of the imperfections.

Figure 13.2.2 Sum of acceptable areas for radiography

Existing Table 13.2.7 has been deleted and replaced with below;

Table 13.2.7 Acceptance criteria for ultrasonic and phased array testing

Echo height	Acceptance criteria
Thicknesses (t) 8 mm – 15 mm	
Signal Amplitudes up to the Reference level (H_o)[1]	Maximum length (l) of discontinuity = $l \leq t$
Signal Amplitudes up to 50% Reference level (H_o)[1] -6dB	Indications with lengths (l) = $l > t$
Thicknesses (t) 15mm – 100mm	
Signal Amplitudes up to the Reference level (H_o)[1] +4dB	Maximum length (l) of discontinuity = 0,5 ≤ t
Signal Amplitudes up to the Reference level (H_o)[1] -2dB	Maximum length (l) of discontinuity = 0,5 $t < l \leq t$
Signal Amplitudes up to the Reference level (H_o)[1] -6dB	Indications with lengths (l) = $l > t$

Note *1*. For depiction and definition of Reference level (H_o), *see Figure 13.2.3 Acceptance level for thicknesses 8 mm to 15 mm* and *Figure 13.2.4 Acceptance level for thicknesses 15 mm to 100 mm*.

Note *2*. For indications exceeding the Evaluation Level, *see Figure 13.2.3 Acceptance level for thicknesses 8 mm to 15 mm* and *Figure 13.2.4 Acceptance level for thicknesses 15 mm to 100 mm* for definition, the length of any discontinuity is to be determined using Maximum Echo Amplitude method.

Note *3*. Grouping of discontinuities based on length and separation of individually acceptable discontinuities producing amplitudes above the Recording Level, for definition (*see Figure13.2.3 Acceptance level for thicknesses 8 mm to 15 mm* and *Figure 13.2.4 Acceptance level for thicknesses 15 mm to 100 mm).* The length of the grouping is not to be used for further grouping.

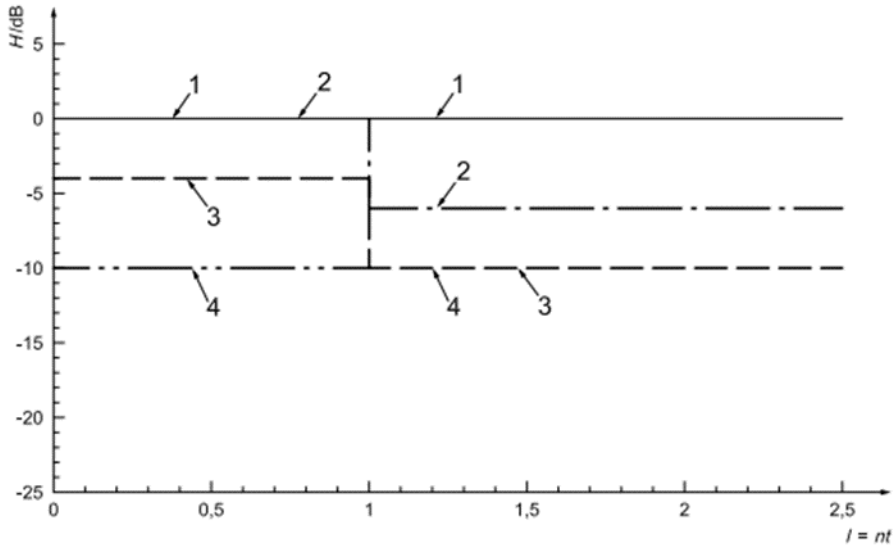
Note *4*. For evaluation, a group of discontinuities is to be considered as a single one if:

(a) the distance along the weld axis (*dx)* between two discontinuities is less than twice the length of the longer discontinuity;
(b) the distance (*dy)* across the weld axis between two discontinuities is less than half of the thickness but not more than 10 mm; and
(c) the distance (*dz)* vertically between two discontinuities is less than half of the thickness but not more than 10 mm.

Note *5*. The combined length of the group of two discontinuities is $l_{12} = l_1 + l_2 + dx$. The combined length l_{12} and the larger maximum amplitude of the two discontinuities is then to be assessed against the applicable acceptance level.

Note *6*. The length of a single acceptable discontinuity above the Recording Level is to be evaluated by assessing the cumulative length of all individually acceptable discontinuities above the Recording level, given as the sum of the lengths of both single and linearly aligned discontinuities of combined length within a given weld length. For any section of weld length $lw = 6t$, the maximum cumulative length lc of all individually acceptable discontinuities above the Recording level is not to exceed 30% of lw.

Note *7*. Guidance on the information provided above can be referenced in ISO 11666.

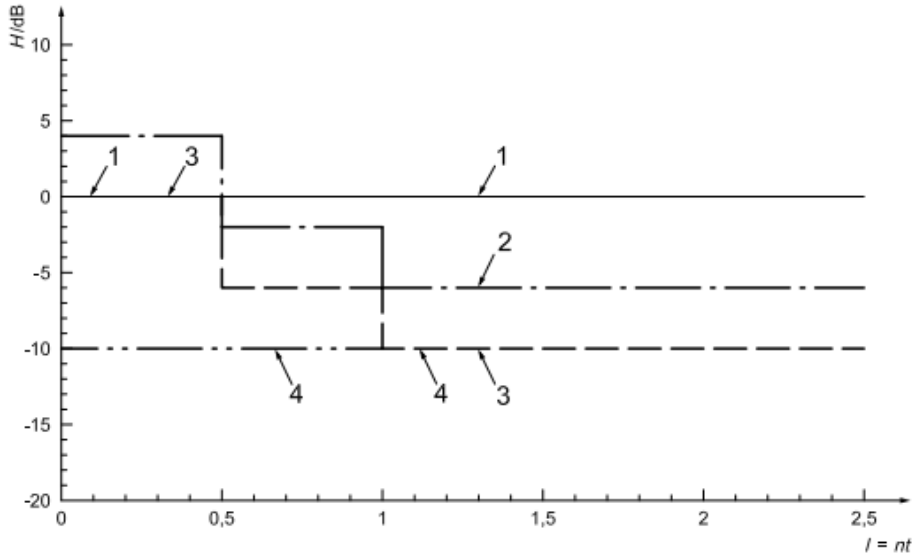


Key:

1. Reference level (H_0): Level defined by the echo amplitude of a defined reference reflector, i.e. 3mm diameter side drilled hole across the thickness range of the weld being tested.
2. Acceptance level: Level defining limits for acceptance regarding echo height, related to length, position, number of indications or size.
3. Recording level: Level above which every echo is to be reported.
4. Evaluation level: Level above which every echo has to be evaluated or needs supplementary examination if further echo signal clarification is required.

H = amplitude level *l* = Indication length *n* = Multiplier of *t* *t* = thickness

Figure 13.2.3 Acceptance level for thicknesses 8 mm to 15 mm



Key:

1. Reference level (H_0): Level defined by the echo amplitude of a defined reference reflector, i.e. 3 mm diameter side drilled hole across the thickness range of the weld being tested.
2. Acceptance level: Level defining limits for acceptance regarding echo height, related to length, position, number of indications or size.
3. Recording level: Level above which every echo is to be reported.
4. Evaluation level: Level above which every echo has to be evaluated or needs supplementary examination if further echo signal clarification is required.

H = amplitude level l = Indication length n = Multiplier of t t = thickness

Figure 13.2.4 Acceptance level for thicknesses 15 mm to 100 mm

Table 13.2.8 Acceptance criteria for TOFD testing[1]

Thickness range (*see* Note 2)	Acceptable length and height of indications		
	Maximum acceptable length if $h < h_2$ l_{max} mm (*see* Notes 3, 5, 6, 7 & 8)	Maximum acceptable height if $l \le l_{max}$ h_2 (for embedded discontinuities) mm (*see* Notes 3, 6, 7, & 8)	Maximum acceptable height if $l > l_{max}$ h_1 mm (*see* Notes 3, 4, 6, 7, & 8)
6 mm < t ≤ 15 mm	t	2	1
15 mm < t ≤ 50 mm	t	4	1
50 mm < t ≤ 100 mm	50	5	2
t > 100 mm	60	6	3

Note *1*. These acceptance criteria are generally based on ISO 15626 level 2 (for embedded discontinuities). *See Figure 13.2.5 General scheme for acceptance conditions* for an overview of acceptance criteria. Further guidance can be referenced within ISO 15626.

Note *2*. Nominal plate thickness. For welds joining two different thickness plates, the thinnest plate is to be taken as the thickness.

Note *3*. When indications from surface-breaking discontinuities are detected, different techniques or methods are to be applied to determine the type or nature of the discontinuity. Using these general (not ECA) acceptance criteria, planar discontinuities such as lack of fusion, lack of penetration, or cracks, are not acceptable if they are surface breaking. If it is not possible to apply other techniques or methods, or accurately determine the type or nature of the discontinuity, then all indications from surface-breaking discontinuities are to be considered as unacceptable.

Note *4*. Indications with heights less than h_1 are not to be considered.

Note *5*. The sum of the lengths of the individual indications with height larger than h_1 measured along the weld over a length of 12 t is to be less than or equal to 4,0 t, with a maximum of 200 mm.

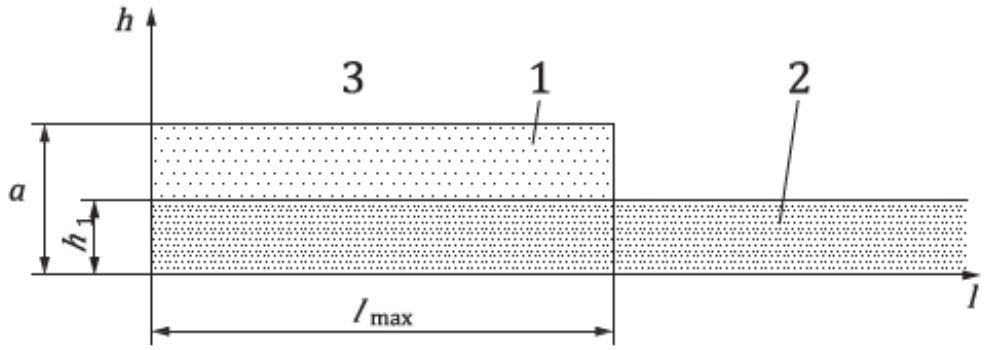
Note *6*. For evaluation, a group of indications is to be considered as a single one if:

- The distance between two individual indications along the weld is less than the length of the longer indication.

- The distance between two individual indications in the thickness direction of the weld is less than the height of the higher indication.

Note *7*. In case of an indication with varying height, the maximum local height, *h*, shall be used.

Note *8*. Point-like indications and indications with height smaller than h_1 are not considered for grouping of indications. Further guidance of the grouping of heights (and local heights), lengths and distance between indications can be referenced in ISO 15626.



Key:
1 acceptance for $l \leq l_{max}$
2 acceptance for $l > l_{max}$
3 Rejection
h_1 Maximum acceptable height for any discontinuity if $l > l_{max}$
a height (h_2) for embedded discontinuities

Figure 13.2.5 General scheme for acceptance conditions

Table 13.2.9 Applicable methods for testing of materials and weld joints

Materials and weld joints	Parent material thickness	Applicable volumetric NDE test methods (*see* Notes 1 & 2)
Ferritic and austenitic stainless steel butt welds with full penetration	Thickness < 6 mm	RT, RT-D
	6 mm ≤ thickness < 8 mm	RT, RT-D, PAUT, TOFD
	thickness ≥ 8 mm	RT, RT-D, UT, PAUT, TOFD
Ferritic and austenitic stainless steel tee joints and corner joints with full penetration	6 mm ≤ thickness < 8 mm	RT, RT-D, PAUT (*see* Note 3)
	thickness ≥ 8 mm	RT, RT-D, UT, PAUT (*see* Note 3)
Ferritic cruciform joints with full penetration	6 mm ≤ thickness < 8 mm	RT, RT-D, PAUT (*see* Note 3)
	thickness ≥ 8 mm	RT, RT-D, UT, PAUT (*see* Note 3)
Ferritic tee joints, corner joints and cruciform joints without full penetration and fillet welds	All	UT, PAUT, RT (*see* Notes 3 & 4)

Note *1*. The method abbreviations are defined in the appropriate sections of *Ch 1, 5 Non-destructive examination.*

Note *2*. TOFD is only applicable to ferritic welds.

Note *3*. RT and RT-D may be applied; however, it is noted that for these configurations, there may be limitations.

Note *4*. UT and PAUT may be used to check the extent of penetration in tee, corner and cruciform joints.

■ *Section 4*
Specific requirements for fusion welded pressure vessels

4.15 NDE method

4.15.1 Volumetric examinations may be made by ~~radiography~~ radiographic or ultrasonic testing, including ANDE methods, and all applicable thickness ranges appropriate to the method, as described in *Ch 13, 2.12 Non-destructive examination of steel welds*. ~~For welds of nominal thickness greater than or equal to 8 mm, the examinations may be by ultrasonic testing.~~ The preferred method for surface crack detection in ferrous metals is magnetic particle inspection. The preferred method for nonmagnetic materials is liquid penetrant inspection.

■ *Section 8*

Specific requirements for welded aluminium

8.4 Non-destructive examination

8.4.1 The requirements of *Ch 13, 1.11 Non-destructive examination of welds* and *Ch 13, 2.12 Non-destructive examination of steel welds* apply with the following additional provisions:~~; however, acceptance criteria applicable to aluminium are to be in accordance with *Table 13.8.2 Acceptance criteria for surface imperfections of aluminium* and *Table 13.8.3 Acceptance criteria for internal imperfections of aluminium.*~~

(a) For full penetration butt welds, the use of advanced NDE (ANDE) methods may be used in lieu of (or complementary to) existing radiographic film testing methods. These methods may additionally be used on other weld configurations, with some limitations, as specified in *Table 13.8.4 Applicable methods for the testing of aluminium weld joints.*

(b) The acceptance criteria for surface imperfections of aluminium welds are to be in accordance with *Table 13.8.2 Acceptance criteria for surface imperfections of aluminium.*

(c) The acceptance criteria for internal imperfections of aluminium welds using RT and RT-D methods are to be in accordance with *Table 13.8.3 Radiographic acceptance criteria for internal imperfections of aluminium*.

(d) The acceptance criteria for internal imperfections of aluminium welds using PAUT (based on length and amplitude) are to be in accordance with *Table 13.2.7 Acceptance criteria for ultrasonic and Phased Array testing.*

(e) The acceptance criteria for internal imperfections of aluminium welds using TOFD are to be in accordance with *Table 13.2.8 Acceptance criteria for TOFD testing.*

(f) Other acceptance standards may be used upon agreement with LR.

Existing Table 13.8.3 has been deleted and replaced with below;

Table 13.8.3 Radiographic acceptance criteria for internal imperfections of aluminium

Internal discontinuity	Classification according to ISO 6520-1	Acceptance criteria (*see* Notes 1 & 2)
Crack	100	Not permitted
Lack of fusion	401	Not permitted
Incomplete penetration	402	Not permitted
Gas pores	2011	$d \leq 0{,}3s$ or $0{,}3a$ or 5 mm max (whichever is the lesser)
Linear porosity	2014	Assess as lack of fusion
Uniformly distributed porosity (*see* Note 3)	2012	$0{,}5 < t < 3$ mm ≤ 2% of area L = 100 mm $3 < t < 12$ mm ≤ 4% of area L = 100 mm $12 < t < 30$ mm ≤ 6% of area L = 100 mm $t > 30$ mm ≤ 8% of area L = 100 mm
Clustered (localised) porosity (*see* Note 3)	2013	dA ≤ 20 mm or dA max ≤ wp (whichever is the lesser)
Elongated cavity and	2015	$l \leq 0{,}3s$ or 4 mm max (whichever is the lesser)
Wormholes (*see* Note 3)	2016	
Oxide inclusion	303	$l \leq 0{,}5s$ or 5 mm max (whichever is the lesser)
Tungsten inclusion	3041	$l \leq 0{,}3s$ or 4 mm max (whichever is the lesser)
Copper inclusion	3042	Not permitted

Symbols

d = diameter of a gas pore

s = nominal butt weld thickness

t = material thickness

wp = width of weld

dA = diameter of area surrounding gas pores

l = length of imperfection in longitudinal direction of weld

L = any 100 mm testing length, in (millimetres)

Note *1*. Any two adjacent imperfections separated by a distance smaller than the major dimension of the smaller imperfection shall be considered as a single imperfection.

Note *2*. Indications shall not be divided into different ranges *L*.

Note *3*. Further guidance regarding determination of porosity areas and summation of acceptable areas may be referenced within the informative annexes of ISO 10675-2.

Table 13.8.4 Applicable methods for the testing of aluminium weld joints

Materials and weld joints	Parent material thickness	Applicable volumetric NDE test methods (*see* Notes 1 & 2)
Aluminium butt welds with full penetration	Thickness < 6 mm	RT, RT-D
	thickness ≥ 6 mm	RT, RT-D, PAUT, TOFD
Aluminium tee joints and corner joints with full penetration	Thickness ≥ 6 mm	RT, RT-D, PAUT (*see* Note 3)
Aluminium cruciform joints with full penetration	Thickness ≥ 6 mm	PAUT

Note *1*. The method abbreviations are defined in the appropriate sections of *Ch 1, 5 Non-destructive examination.*

Note *2*. Ultrasonic testing may be specially considered upon agreement with LR.

Note *3*. RT and RT-D may be applied; however, it is noted that for these configurations, there may be limitations.

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